LOADS PREDICTION PROGRAM FOR ACCIDENTAL EXPLOSIONS IN UNDERGROUND MUNITIONS STORAGE FACILITIES

Arnfinn Jenssen, Norwegian Defence Construction Service
Chester Canada, DOD Explosives Safety Board
Charles Needham, Maxwell Laboratories, S-Cubed Division
Lynn Kennedy, Maxwell Laboratories, S-Cubed Division

ABSTRACT

The KLOTZ Club is a multi-national group of explosives safety specialists concerned with the safe storage of military ammunition and munitions. One topic of present interest to the KLOTZ Club is the effects of the hazardous environment that would result from an accidental explosion in an underground military munitions storage facility. The necessary placement and/or design of nearby above-ground structures, to provide the required degree of safety for their occupants, is of concern. A knowledge of the predicted hazardous environments, and the resulting loads on the structures (blast, impulse, debris, ground shock, and thermal flux), is required if the prescribed degree of safety is to be provided.

For an above-ground storage facility, only a few parameters are needed to characterize the effects. An underground facility, however, requires the consideration of a number of variables if safety hazards are to be adequately predicted and mitigated. In order to properly account for this multitude of parameters, the KLOTZ Club decided, at its 1990 working group meeting, to sponsor development of a "Loads Prediction Computer Program for Underground Storage of Military Munitions". As presently conceived, the program is to run on an AT or 386-class personal computer. It is to be able to predict the details of the hazards expected from accidental detonation of the stored explosives within the facility with sufficient accuracy to permit revision of storage plans for existing facilities and design of planned facilities, as well as siting and design of occupied structures to be built near to or contiguous with the facilities. Loads prediction capabilities for a wide range of site-specific underground storage facility designs are planned. All parameters that significantly influence hazardous loading environments will be considered. These will include such factors as facility geometry and size, composition and competency of the earth cover, the explosive material and its storage and packaging configuration, effective loading density, and geology. The pro-

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **AUG 1990**	2. REPORT TYPE	3. DATES COVERED **00-00-1990 to 00-00-1990**

4. TITLE AND SUBTITLE **Loads Prediction Program for Accidental Explosions in Underground Munitions Storage Facilities**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Maxwell Laboratories,S-Cubed Division, ,Albuquerque,NM,87106**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADA235006, Volume 2. Minutes of the Explosives Safety Seminar (24th) Held in St. Louis, MO on 28-30 August 1990.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**12**	

gram will be based on available experimental results (both large- and small-scale), on computational analyses, and on an understanding of the physics of the detonation and its interaction with the facility and the structures. The undertaking is a large as well as significant one, and may take several years to complete. However, the predictions should prove extremely useful for both the proper siting and design of planned underground storage facilities and for assessing risks related to various storage configurations in existing facilities.

1. Introduction.

A topic of current and continuing interest to the KLOTZ Club membership and other explosives safety specialists, both military and civilian, is the effects of the hazardous environment that would result from an accidental explosion in an underground munitions storage facility. The KLOTZ Club, at its 1990 working group meeting, decided, as part of its work toward quantifying these effects, to undertake development of a PC-based program aimed at predicting these hazardous environments and the loads resulting from them. This paper presents a brief summary of the authors' thoughts over the past year on why such a program is needed, what it should be expected to do, and how development of such a program should be approached.

Underground storage, for purposes of this discussion, is taken to include both deeply-buried facilities, whose covers do not rupture as a result of explosion of their prescribed load of explosives and propellants, and shallow-buried facilities, whose covers will rupture. In the former case, the major hazard is from directional blastwaves, debris, and burning gases emerging from portals or vent openings. In the latter case, the rupturing overburden may contribute to the debris hazard, and the blast, debris, and thermal hazards are not directionally contained.

For an above-ground storage facility, only a few parameters are generally needed to characterize the hazardous effects. An underground facility, however, requires the consideration of a number of variables if the safety hazards are to be adequately predicted and mitigated. These variables include the type, amount, and configuration of the explosive/propellant load, the facility geometry and size, the composition, competency, geology, and geometry of the earth cover, and features of the terrain exterior to the facility. Because of the large number of parameters, an engineering table

or simple algorithm is not adequate to provide the desired results. This has been shown on numerous occasions, when attempts have been made to provide "quick" predictions for experimental tests. The predictions have sometimes proved to be "off" by as much as an order of magnitude. As an illustration, Figure 1 shows the range of predictions that were provided for a test in 1988 at the US Naval Weapons Center, China Lake.

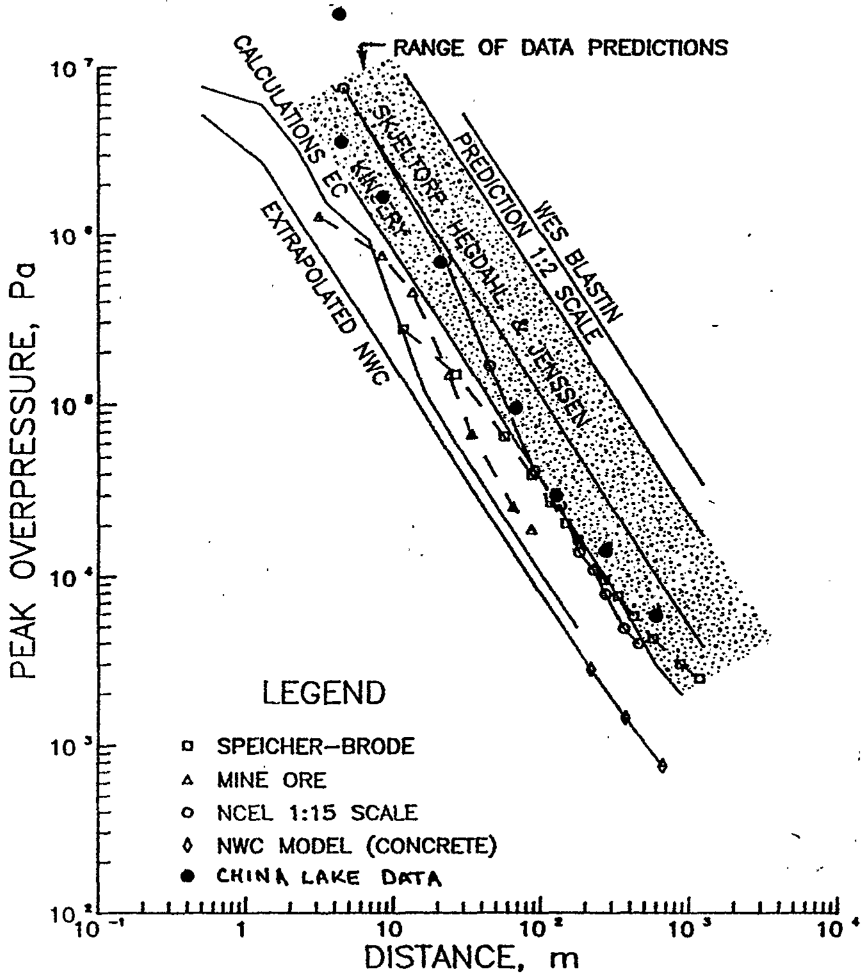

Figure 1: Airblast Predictions for Shallow-Buried Underground Tunnel/ Chamber Test at China Lake.

For this reason, an easy-to-use PC or workstation-based program is needed to generate the environments of interest. Such a program should be sufficiently rugged that it could be used to investigate the effect of proposed changes of size, geometry, etc. It should also be well-documented, so that it could be used by test engineers as well as by facility

designers (to address safety issues in planned facilities) and site managers (to assess risks related to various storage configurations in existing facilities). Finally, its ranges of applicability and its degree of accuracy in various regions needs to be carefully defined and documented.

2. Need for Program.

a. Design of New Facilities.

One major area in which the planned program is needed is for the design of new facilities. Underground storage of munitions is becoming more attractive, both because it is perceived to be safer than above-ground storage, and because of increasing scarcity and cost of real estate to provide an adequate cushion of space around above-ground facilities. Although many governments and industries need to stockpile explosives and propellants, both for defense and for peacetime uses, many of them may not have the resources or the space available to provide this cushion. In planning for storage, it is necessary to plan precisely, using highly accurate planning tools, in order to maximize storage capabilities and minimize costs. The use of berms, debris catchers, blast traps, blast doors and other devices, plus the use of terrain features to protect nearby structures and personnel, are all possible design features that might be incorporated in new facilities to increase their safety or to reduce the real estate required for safety zones.

b. Maximization of Loading in Existing Facilities.

Because of increased environmental awareness and increasingly stringent regulations regarding the storage of explosive and propellant materials, coupled with the need for additional storage capabilities, many organizations are seeking to expand, or at least to justify the safety of, the loads allowed in currently-existing facilities. In order to do this, a highly accurate and thoroughly validated hazardous environment prediction capability is needed. The site manager may wish to assess a number of different storage configurations, and thus to evaluate how he might best arrange his particular mix of explosives and propellants to provide complete compliance with all safety regulations, and hence maintain the highest degree of safety for on-site employees and adjacent areas where people may live or work.

c. Inadequacy of Existing Programs.

Although some algorithms and models currently exist for the prediction of environments from explosions in underground storage facilities, these are generally specialized to apply to a particular type of facility or a particular configuration. They may also predict only a single type of hazardous environment. For a given planned test configuration, predictions, as previously mentioned, may vary by an order of magnitude. Such variations in predictions make it difficult for experimenters even to set a range for gauge responses. For facility designers, the uncertainty is frustrating.

A start has been made, and several factors now make it practical to attempt a comprehensive program for prediction of environments from underground munitions storage facilities:

1) A data base of high explosive and propellant information is being compiled which directly relates to this problem.

2) Hydrodynamic code capabilities are sufficiently advanced that they can deal with these configurations, and preliminary validation runs show excellent correlation with experimental data. An example of the correspondence between experimental and calculated results is shown in Figure 2. The test was the one at China Lake, and the calculation was run with the S-CUBED hydrocode SHARC.

3) New personal computers are extremely powerful and can run relatively complex programs in an interactive mode. In addition, the use of these personal computers is becoming widespread.

3. Requirements for Program.

In deciding how to proceed in constructing a PC program to provide the desired information, two lists need to be made. The first is a list of the environments we want to predict. These are the environments which we believe will prove to be the most hazardous to buildings and personnel in the area of the storage facility and those environments inside the facility which may lead to the spread of fires as well as to prompt or delayed detonation of other munitions stored there. The second is a list of variables which will describe the detonation and the facility, and hence will affect the hazardous environments. These variables will be used as inputs to the PC program. A preliminary version of both of these lists, with discussion of each item, is given in the following two subsections.

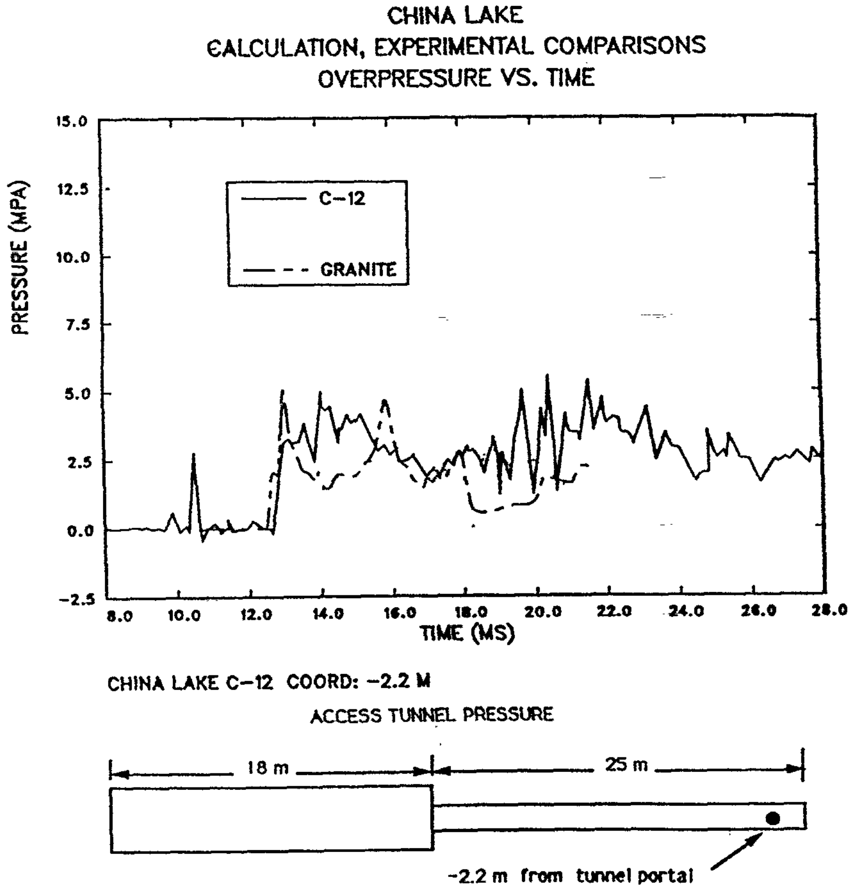

Figure 2: Comparison of Experimental and Calculated Overpressure Records from the China Lake Test.

a. Prediction of Environments and Loads.

There are four types of environments/loads currently being considered for inclusion in the PC program. The first, and the first to be addressed, will be airblast, because a great deal of work has already been done in this area and the tools to define it, the hydrodynamic codes, are in place. Within the airblast investigation, not only overpressure will be considered, but also impulse, dynamic pressure, and dynamic pressure impulse. Dynamic pressure is one of the primary parameters significant in structure and vehicle damage, and it is also active in the pickup and acceleration of debris. Impulse is the parameter usually provided as input to structural response calculations.

A second environment/load of interest will be the debris hazard. Debris can come from shell casings, packaging materials, and equipment contained with the explosive/propellant in the facility, or it can come from the geologic materials and concrete structures which form the overburden. The size distribution and directional acceleration of these debris materials by the airblast or ground shock environment can make them a significant hazard, both within the facility and outside. Once accelerated, heavy pieces of debris can travel for long distances, because they are slowed only by air drag forces.

Ground motion is thought at this point to be less significant than the two environments/loads mentioned above, because it is generally not so severe at close-in ranges. Depending on the size of the explosive charge, the range of interest, the geological configuration, and the strength of the affected structures, it could be important in some cases. Hydrodynamic and elastic-plastic codes are available to investigate the ground motion environment, and there is some data.

Thermal environments are included for consideration because, in cases of incomplete detonation or of ignition of propellants, gases may be produced which are burning as they are swept out of the facility. Temperatures inside the facility are also a consideration for sympathetic detonation. For a large, shallow-buried facility, a fireball will be formed which could ignite nearby structures if they are not provided with some protection. The possibility also exists that unprotected personnel may be working in the area. The flow fields governing the movement of these gases, the ignition of auxiliary fuels with which they may come in contact, and the resulting thermal radiations are subjects which need to be addressed.

b. Variables.

The list of input variables which will need to be included for the PC program is necessarily incomplete at this time. We expect that the list will be revised as new factors are found to be needed, old factors are dropped because they are determined to be unimportant, and new ways are discovered to describe or define significant factors. The discussion in this section describes three comprehensive areas which will need to be included. The best way to describe the various input parameters in these areas has yet to be determined.

The first group includes descriptors of the explosive charge itself: the amounts and kinds of explosives and/or propellants, the packaging or casings containing and separating the various components, and the storage or stacking arrangements. Amounts/kinds will determine the total energy release as a result of the contemplated incident. Packaging/casings will determine the amount and timing of sympathetic detonations, and will contribute to the debris available to be accelerated. Stacking arrangements will also possibly be significant in this regard.

A second group of descriptors involves the internal configuration of the facility: the sizes of the storage chambers and the cross sectional areas, lengths, and curvatures of associated access tunnels. Internal separating walls and blast doors or debris traps may also be included in this category. The amount, materials, and properties of the overburden, which determine when or if it ruptures and how much energy it absorbs, should also be considered.

Finally, the external configuration will affect the hazardous environments. Terrain features, the existence and placement of berms and debris catchers, and the geology of the earth in the vicinity will be factors. In addition, the distance of structures from the storage facility, their placement relative to openings, and their strength and integrity should be considered. Proposed uses of these structures or equipment will be factors in determining the allowable environments at various locations.

4. Approach.

It is anticipated that the first environment to be investigated will be airblast. This is because a fair amount of work has already been done in this area: data is available and some preliminary correlations have previously been made. This should lead to the generation of a workable PC model for airblast within about a year. The steps to be accomplished in developing the airblast model are outlined below. Development and subsequent improvement of models for the other environments should proceed in a similar manner. It is expected that the models for each individual environment will be combined into an integrated program in which all possible hazardous effects can be investigated.

a. Review of Available Data.

The first step in the process of preparing an environments prediction model should be a review of currently available airblast data from tests and theoretical calculations. The data should be examined and sorted according to its applicability to configurations of interest and according to the completeness of information about the yield and configuration of the explosion which generated the data. Cause-and-effect correlations should be identified. It is emphasized that review of the data must be accomplished with the physical principles that govern airblast generation and propagation kept firmly in mind. This will allow the reviewers to identify inconsistencies in the data and to discard any data that seems to be incorrectly recorded or identified.

b. Review of Current Models and Definition of Regions of Inadequacy.

At his stage, the correlations and normalizations of the data provided by all researchers should be examined. Two such correlations are those by Skjeltorp, Hegdahl & Jenssen and by Kingery. Some of the current models have been developed by entering peak pressure data on a pressure vs. range logarithmic grid. The data is then fit by a straight line which defines an inverse power for decay of peak pressure with range. Although this is a powerful technique, we now know that a single value of the decay exponent is not appropriate for all ranges. By using a more comprehensive algorithm, a better fit to the data can be obtained which will provide good results over a broad range of pressure values. In addition, an estimate of the accuracy of the fits, both within the range of the data and beyond it, can be obtained.

c. Validation of Calculational Tools.

It is anticipated that the experimental data will be found to be insufficient for generation of a complete model. This is because the nature and cost of experiments require that data be collected at only a few points and for only a few selected configurations. In order to provide for a complete understanding of blast wave propagation, data at a large number of locations, and information about the variation of other hydrodynamic parameters (for example, density and gas flow velocity) as functions of time and space are needed. For this reason, we expect to include the results of numerical hydrodynamic calculations in the data base. A few calculations

have previously been accomplished, and these have been used to validate the procedures. In particular, three-dimensional calculations have been completed simulating recent tests at China Lake (California) and Ælvdalen (Sweden). The results of these calculations are to be reported at this Seminar by representatives from S-Cubed, Albuquerque, New Mexico.

d. Performance of Selected Parameter Studies with Calculations.

Once we are satisfied that the calculational techniques are valid, calculations can be performed to fill in gaps in the experimental data base and to perform parameter studies. The results of these calculations will help us to understand how the parameters listed above affect the airblast environments in regions of interest. The suite of calculational configurations should be carefully chosen to minimize both the number and complexity of calculations to be performed. Calculations, like large-scale tests, can be expensive, and it is important that they be carefully designed to maximize useful output. It is expected that the calculations will concentrate initially on high explosive sources. Techniques also exist, however, for calculating the results from propellant burning. Both types of sources, and mixtures of the two, are of interest for the final model.

e. Analysis of Calculations.

A thorough analysis of completed calculations is necessary to obtain a full understanding of the physics applicable to each situation. Not only overpressure peak values, but complete waveforms should be studied to determine origins of the various features which affect the blast environment. All basic and derived hydrodynamic parameters (pressure, impulse, density, flow velocity, energy, temperature, gas composition, and dynamic pressure) should be considered.

f. Development of Models.

Once a relatively complete data base is assembled, consisting of experimental data and calculations and including an understanding of the physical principles which give rise to the observed results, mathematical algorithms can be developed which, as functions of the various parameters identified as significant, can reproduce the observed environments. These algorithms can be mathematical expressions, tables from which numerical

answers are interpolated, and rules for combinations of results from several sources. An important part of model development is the assurance of physical consistency. If care is not taken, "glitches" can occur which produce unreasonable results for some combinations of variables.

g. Model Testing.

As the models are developed, they can be tested against the available data, both calculational and experimental, to ascertain whether or not they are providing reasonable answers which agree in all respects with the data. At this point, it will be appropriate to conduct some new experiments, either at large- or small-scale, so that the models can be tested against data which was not used in building the models. The experiments should be designed to exercise as many aspects of the models as possible. Comparison of results will provide a basis for judging the accuracy of the models in a real prediction situation.

h. Incorporation of Models into PC Program.

The validated models will the be incorporated into a personal computer or work station program. This is a straight-forward activity, but must be accomplished with care if the results is going to be useful to a variety of users. The most important part of this step is development of the user-interface menus so that they are understandable and logically organized. Another important part is development of documentation, either on-line or as separate documents. All aspects of the code and how it works must be carefully explained if misuse by inexperienced workers is to be avoided.

i. Refinement and Improvement of Models.

Finally, further refinement of the models should be undertaken to incorporate the other environments of interest and to accommodate new data or new configurations which were not covered in the first round of development. The cycle of data review, calculations and analysis, preliminary development of models, testing, and incorporation into the PC program can be followed through for debris, using much of the same experimental and calculational data used for the airblast investigation. Our experience has been that models of this type are never fully completed, because a completed capability always leads to the desire to apply the model to new situations. These new situations point up deficiencies, which in turn re-

quire new development, new analysis, and new testing. The product then, which is the PC program, can continue to be improved even while it is being used and providing useful results.